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An energy-momentum time integration scheme based on a convex multi-variable framework for non-linear electro-elastodynamics

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Abstract

This paper introduces a new one-step second order accurate energy-momentum (EM) preserving time integrator for reversible electro-elastodynamics. The new scheme is shown to be extremely useful for the long-term simulation of electroactive polymers (EAPs) undergoing massive strains and/or electric fields. The paper presents the following main novelties. (1) The formulation of a new energy momentum time integrator scheme in the context of nonlinear electro-elastodynamics. (2) The consideration of well-posed *ab initio* convex multi-variable constitutive models. (3) Based on the use of alternative mixed variational principles, the paper introduces two different EM time integration strategies (one based on the Helmholtz's and the other based on the internal energy). (4) The new time integrator relies on the definition of four discrete derivatives of the internal/Helmholtz energies representing the algorithmic counterparts of the work conjugates of the right Cauchy-Green deformation tensor, its co-factor, its determinant and the Lagrangian electric displacement field. (5) Proof of thermodynamic consistency and of second order accuracy with respect to time of the resulting algorithm is included. Finally, a series of numerical examples are included in order to demonstrate the robustness and conservation properties of the proposed scheme, specifically in the case of long-term simulations.

Keywords: electroactive polymer, electro-elastodynamics, multi-variable convexity, energy-momentum scheme.

1. Introduction

Electro Active Polymers (EAPs) [41, 40, 42, 29] represent an important family of smart materials where dielectric elastomers and piezoelectric polymers are some of their most iconic integrants. Dielectric elastomers are very well-known for their outstanding actuation capabilities and low stiffness properties, which makes them ideal for their use as *soft robots* [35]. For instance, electrically induced area expansions of over 380% on dielectric elastomer thin films placed on the verge of snap-through configurations have been reported by Li et al. [30]. Other applications for dielectric elastomers include Braille displays, deformable lenses, haptic devices and energy generators, to name but a few. [14]. Piezoelectric polymers have similar dielectric properties to dielectric elastomers but, on the other hand, have much larger stiffness. As a result, piezoelectric polymers cannot in principle exhibit large electrically induced deformations. Instead, they can be used as moderately deformable actuators. Other important type of applications for these materials include tactile sensors, energy harvesters, acoustic transducers and inertial sensors [35, 14].

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